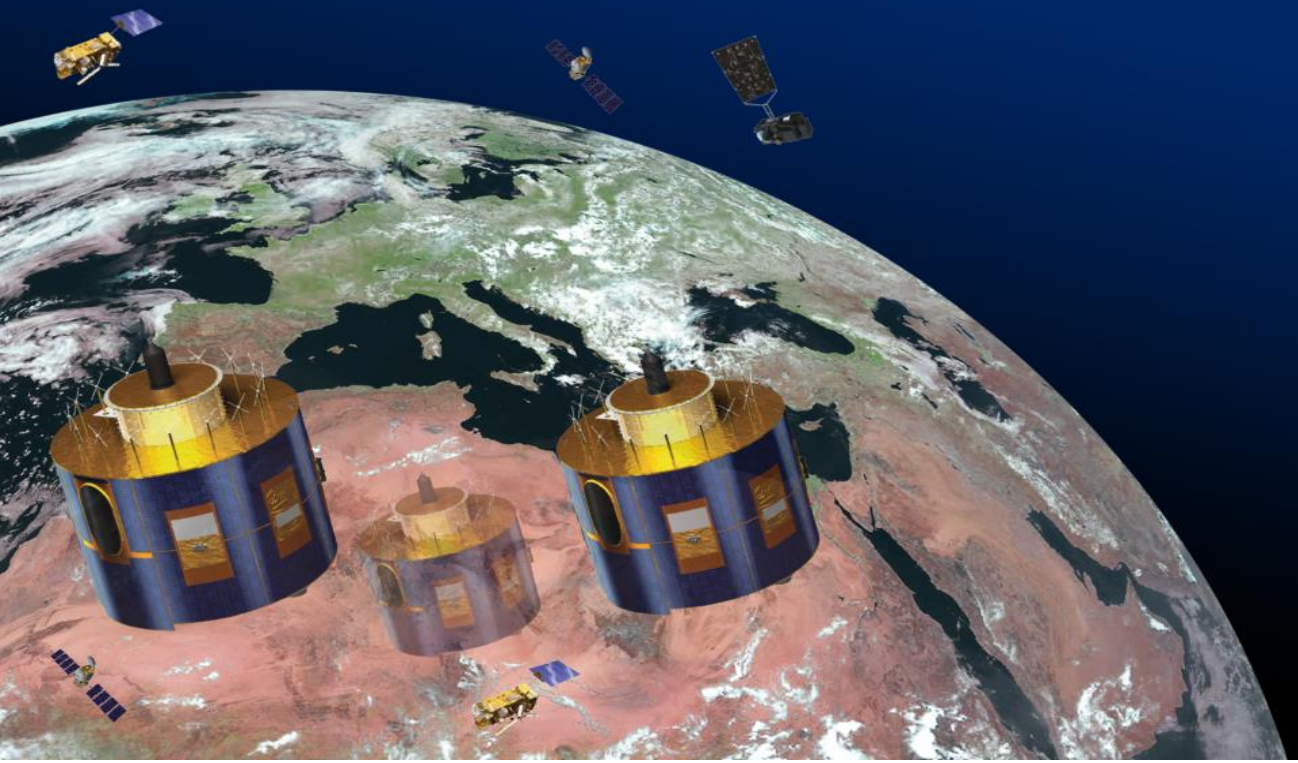
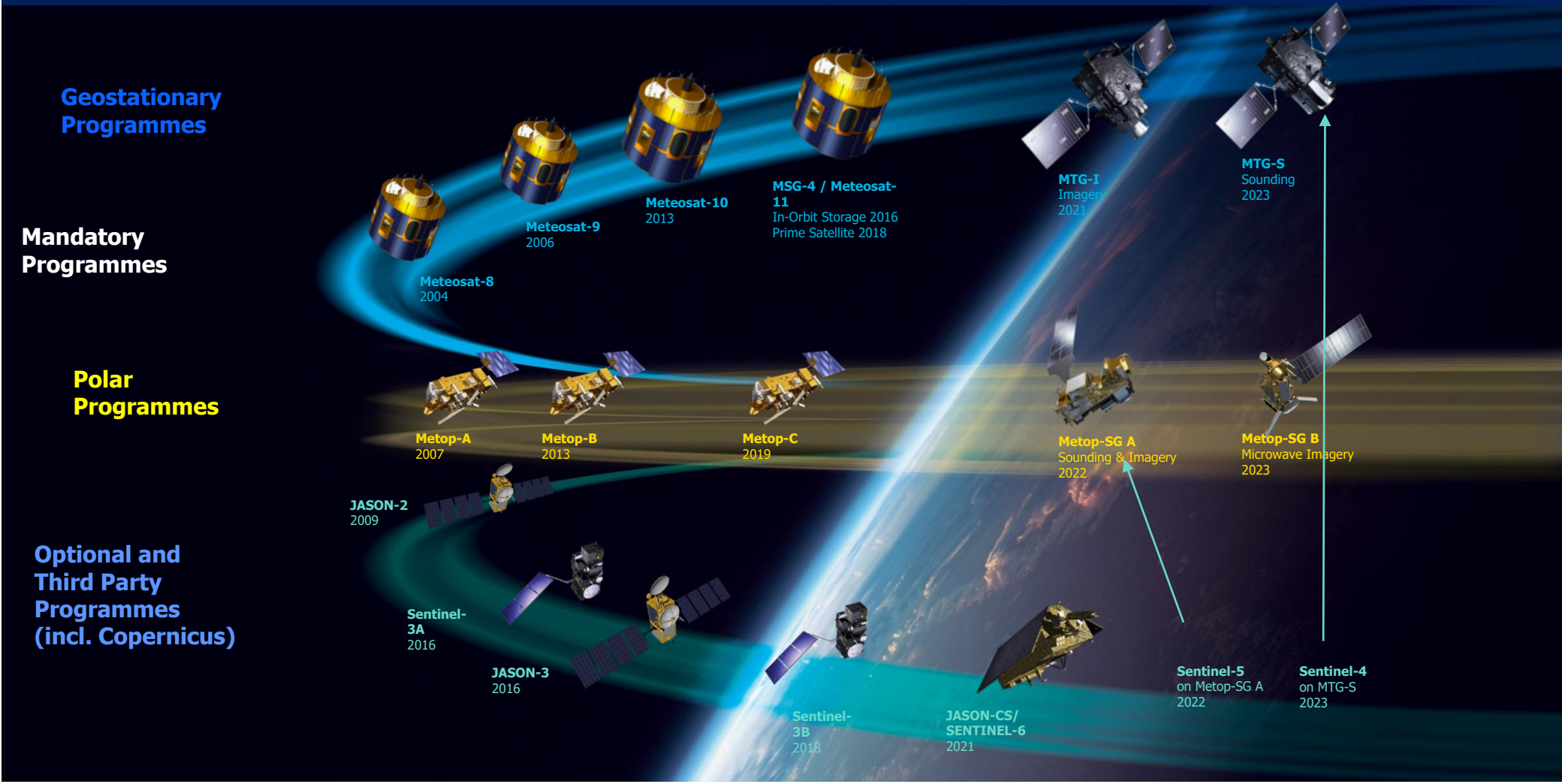
Science developments for EPS-SG

Peter Schlüssel



EUM/RSP/VWG/18/1011769, v1, 23 August 2018

EUMETSAT missions – current and future



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EPS-SG benefits to activities of NMSs

Main Payload	Enhanced Capabilities	Innovative Capabilities	Applications Benefiting
High-Resolution Infrared Sounding **(IASI-NG)**	+75% information in T-profiles +30% in WP-profiles	More trace gases and their vertical profiles	NWP, NWC, AC, CM
Microwave Sounding **(MWS)**	Enhanced spatial over-sampling	Ice-cloud info in support of water-vapour profiling	NWP, NWC, CM
Radio Occultation Sounding **(RO)**	Large increase of number of radio-occultations	Tracking of Galileo, Beidou and QZSS signals	NWP, CM
Nadir viewing UV/VIS/NIR/SWIR Sounding **(Sentinel-5)**	Drastic increase of spatial resolution	Additional trace gas measurements; CO_2 being studied	Air Quality, CM, AC
VIS/IR Imaging **(METimage)**	Better radiometric and spatial resolution	Far more variables measured with higher accuracy	NWC, NWP, CM
Scatterometry **(SCA)**	Higher spatial resolution and coverage	Cross polarisation for higher wind speeds	NWP, NWC, CM
Multi-viewing, -channel, -polarisation Imaging **(3MI)**	New mission	Aerosol parameters	Air quality, CM, NWC
Microwave Imaging **(MWI)**	New mission	Precipitation observations	NWP, NWC, Hydrology, CM
Ice Cloud Imaging **(ICI)**	New mission	Cloud microphysics parameters	NWP, NWC, Hydrology, CM

NWP: Numerical Weather Prediction; NWC: Nowcasting; CM: Climate Monitoring; AC: Atm. Composition

EPS-SG space segment

Two satellite configuration

- **Metop-SG-A**
  - IASI-NG
  - METimage
  - MWS
  - 3MI
  - Sentinel-5
  - RO
- **Metop-SG-B**
  - SCA
  - MWI
  - ICI
  - RO
  - ARGOS-4

Scientific preparations for EPS-SG

Objectives

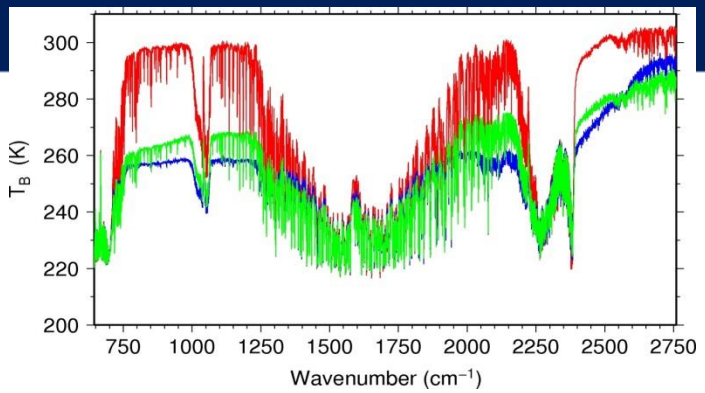
- Recognize the importance of continuity of service to the users
  - Avoidance of data gaps
  - Continue products with same or better performance than EPS first generation
- Product generation
  - Primary focus on Level 1
  - Continuity of existing level 2 products
  - Innovative level 2 products exploiting new instrument characteristics
  - New level 2 products, primarily for new instruments: 3MI, MWI, ICI
- Cal/Val Planning
  - Commissioning phase will last 6 months, after which the products have to be declared operational and be operationally disseminated to users
  - Limitation of activities to the mandatory ones to provide validity status of the products
  - Involvement of main users in commissioning
  - Beneficial activities can continue after commissioning to gain further confidence in product quality
  - Product validation and operational monitoring will continue beyond commissioning to ensure continuity of product quality and to identify any anomalies

Sounding missions

Measure the vertical distribution of the atmospheric state

- Infrared Atmospheric Sounding Interferometer – New Generation (IASI-NG)
- Micro-Wave Sounding (MWS)
- Radio Occultation Sounding (RO)
- Nadir viewing UV/VIS/NIR/SWIR Sounding (Sentinel-5)

Hyper-spectral infrared sounding (IASI – NG)



Objectives / products

- Temperature/humidity profile at high vertical resolution in clear air
- Clouds, trace gases (O_3, CO, CH_4, CO_2,...)
- Sea/land/ice surface temperature
- Aerosols, Volcanic Ash

Key performances

- Spectral range: 645 – 2760 cm^{-1}
- Spectral resolution: 0.25 cm^{-1}
- Radiometric calibration: 0.25 K
- Stability: 0.1 K
- Radiometric noise: 0.045 – 1.1 K
- Pixel size: 12 km
- Spatial sampling: 25 km
- Cross-track scan

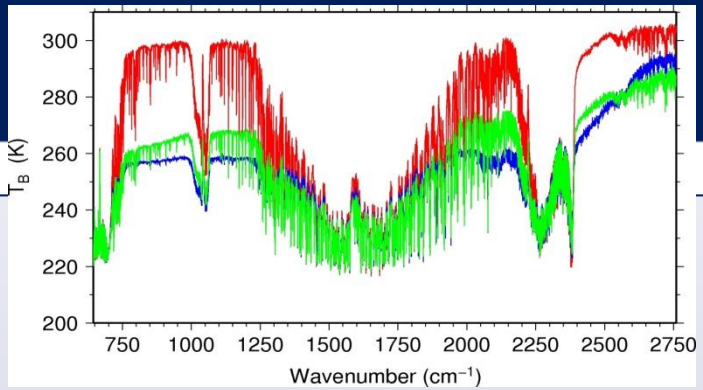
Applications benefitting

- Numerical weather prediction
- Nowcasting
- Climate monitoring
- Oceanography
- Atmospheric composition

Breakthrough

- **Doubling of radiometric and spectral resolution of IASI for the benefit of weather forecast and atmospheric composition**
  - 75% more information in temperature profiling, particularly PBL
  - 30 % more information in water vapour profiling
  - Quantification of trace gases which are currently only detected
  - Vertical resolution of trace gases instead of columnar amounts only

Hyper-spectral infrared sounding (IASI – NG)



Level 1C product

- **Being implemented by CNES**

Level 1D product

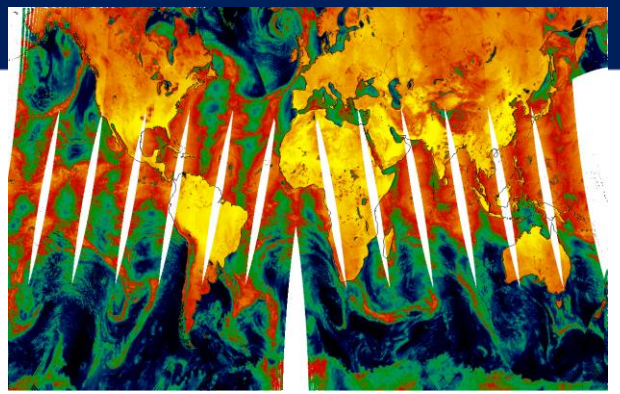
- **Principal component scores of Level 1C spectra**
  - No new development needed, adaptation of methodology from IASI

Level 2 products

- **Continuation of IASI Level 2**
  - Re-use of methods developed for IASI at Day-1
  - Averaging of IASI-NG spectra to mimic IASI spectra thereby benefitting of lower noise
  - Lower errors in products

  - Day-2 developments of new products together with SAF on Atmospheric Composition
  - Activities ongoing for new or improved trace gas and cloud product
  - Combined IASI-NG/MWS products being developed

Micro-wave sounding (MWS)



Objectives / products

- Temperature/humidity profiles in clear and cloudy air
- Cloud liquid water total column
- Imagery: precipitation

Key performances

- 24 channels: 23.8 – 229 GHz
- Absolute calibration: 0.5 K
- Radiometric noise: 0.2 – 1.6 K
- Footprint size: 17 – 40 km
- Cross-track scan

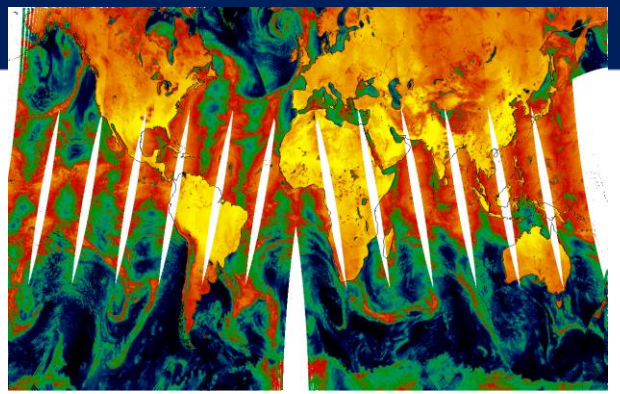
Applications benefitting

- Numerical weather prediction
- Nowcasting
- Climate monitoring

Breakthrough

- **Addition of a quasi-window channel at 229 GHz (recommended by ITSC-11)** (MWS)
  - Cirrus cloud information giving a better humidity retrieval performance
- **Addition of sounding channels**
  - **+ 2 channels at 53-54 GHz**
  - **+ 3 channels at 183.31 GHz**
  - More information on temperature and water vapour profiles

Micro-wave sounding (MWS)



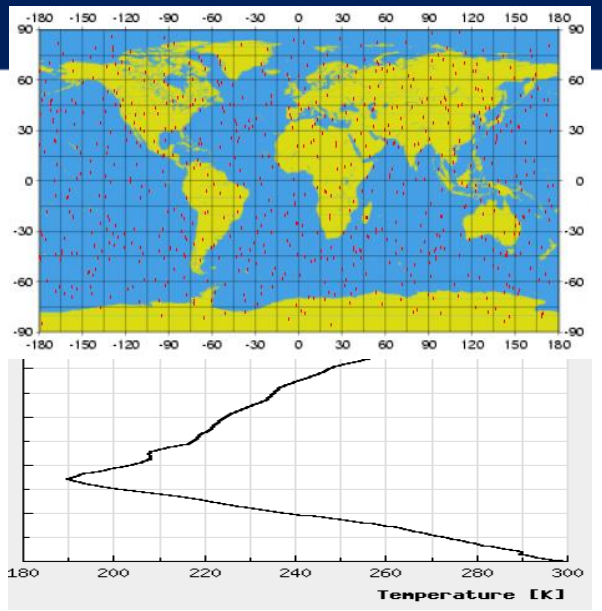
Level 1B

- **Being implemented following industrial ATBD**

Level 2

- **Total precipitable water**
  - Continuity of AMSU-A/MHS product

Radio occultation sounding (RO)



Objectives / products

- Refractivity profiles at high vert. resolution
- Temperature / humidity profiles
- PBL top and tropopause height
- Ionospheric electron content

Key performances

- Tracking of GPS and Galileo satellites
- Optional: Beidou and QZSS
- RO on two satellites: > 2600 occultations per day
- Bending angle accuracy: 0.5 µrad or 0.2%

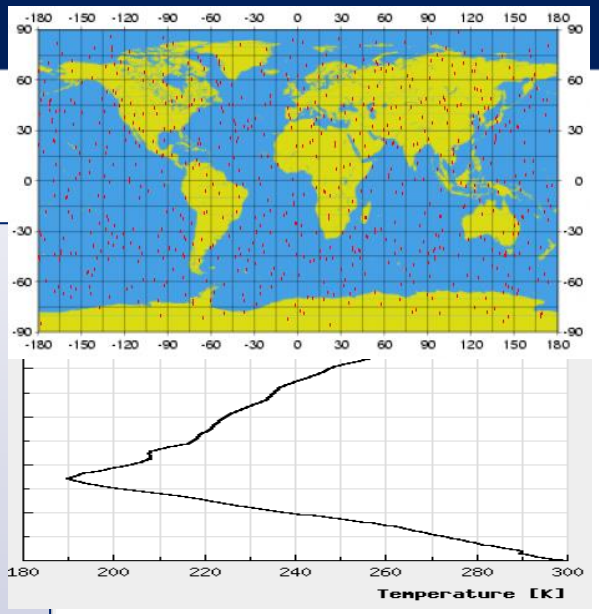
Applications benefitting

- Numerical weather prediction
- Climate monitoring
- Space weather

Breakthrough

- **Tracking of GPS and Galileo satellites to double the number of occultation measurements**
- **Equipment of both Metop-SG satellites with RO in case of a dual satellite configuration**

Radio occultation sounding (RO)



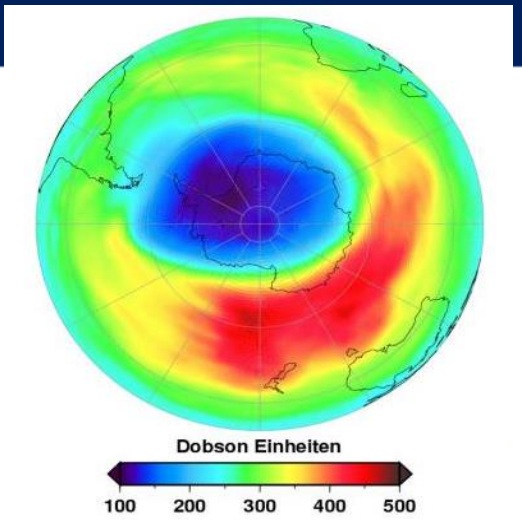
Level 1B

- **Addition of new GNSS constellations:**
  - **Galileo**
  - **Beidou**
  - **QZSS**
- **Inclusion of new Precise Orbit Determination (POD)**

Level 2

- **Work on space weather products (ROM SAF)**

Nadir viewing UV/VIS/NIR/SWIR sounding (Sentinel-5)



Objectives / products

- Ozone profile and column
- Columns of CO_2,SO_2, NO_2, H_2O, CO, CH_4,
- Aerosol optical depth
- Columns of BrO, HCHO, OCHCHO
- Volcanic Plumes

Key performances

- Spectral range: 0.27 – 2.385 µm
- Spectral resolution: 0.25 – 1 nm
- Radiometric calibration: 1 – 2%
- SNR: 120 - 1500
- Spatial sampling: 7 km
- Cross-track scan

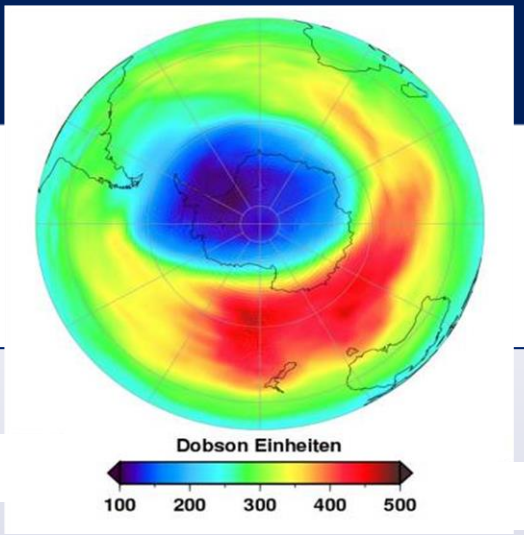
Applications benefitting

- Air quality forecasting
- Ozone-UV
- Atmospheric Composition
- Climate monitoring

Breakthrough

- **Drastically increased spatial sampling (7 km)**
  - for the benefit of air quality monitoring
- **Extended spectral range into the near and shortwave infrared regions**
  - to measure aerosols as well as methane and carbon monoxide in the PBL

Nadir viewing UV/VIS/NIR/SWIR sounding (Sentinel-5)



Level 1B

- **Being implemented following industrial ATBD**

Level 2 products

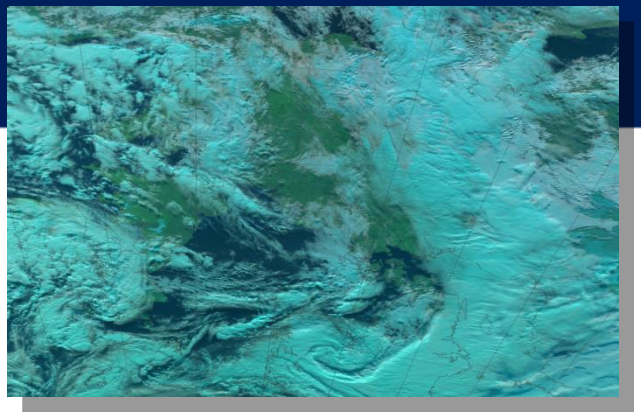
- **Development by ESA on behalf of Copernicus**
  - 18 trace gas, aerosol, and surface products
  - Processing will be implemented at EUMETSAT HQ for NRT dissemination
- **Further products being developed by the SAF on Atmospheric Composition**
  - 4 trace gas products

Imaging missions

Measure the horizontal distribution of clouds, aerosols, and surface variables

- Visible/Infra-red Imaging (METimage)
- Multi-viewing, -channel, -polarisation Imaging (3MI)
- Micro-wave Imaging (MWI)
- Ice Cloud Imaging (ICI)
- Scatterometry (SCA)

Optical imaging (METimage)



Objectives / products

- Hi-res cloud products, incl. microphysics
- Aerosols
- Polar AMVs
- Vegetation, snow, fire
- Sea/ice/land surface temperature
- Support to sounding missions

Key performances

- 20 channels: 0.443 – 13.345 µm
- Absolute calibration: 5% (short-wave)
- 0.5 K (long-wave)
- Radiometric sensitivity:
- SNR 60 – 500 (short-wave)
- 0.05 – 0.2 K (long-wave)
- Spatial sampling: 500 m
- Cross-track scan

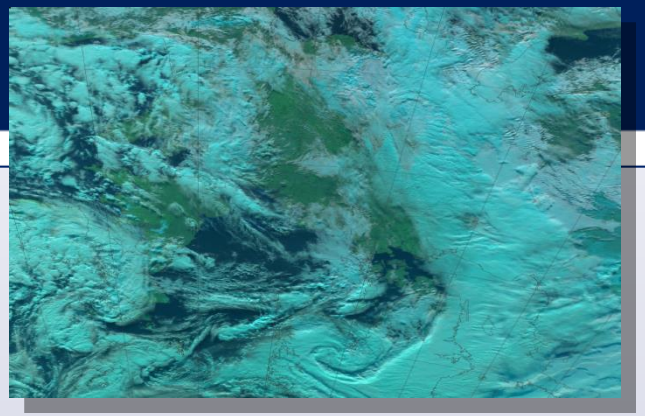
Applications benefitting

- Nowcasting
- Numerical weather prediction
- Oceanography
- Hydrology
- Climate monitoring

Breakthrough

- **Far more spectral channels than AVHRR for the benefit of measuring more variables**
- **Higher spatial sampling (500 m):**
  - more complete coverage through greater likelihood to measure surface variables in partly cloud conditions
- **Better radiometric resolution for more accurate quantification of many variables**

Optical imaging (METimage)



Level 1B

- **Being implemented following industrial ATBD**

Level 2 Cloud Mask product

- **In support of IASI-NG, S-5, 3MI**
  - **Fast algorithms to allow usage of product in other product processing**
  - **Will be part of Level 2 product**

Level 2 products

- **Centrally generated**
  - 7 cloud variables, total precipitable water, polar atmospheric motion vectors, volcanic ash
- Products developed by SAFs on Hydrology, Land Surface Analysis, Ocean and Sea Ice
  - Theme-oriented Level 2 and Level 3 products

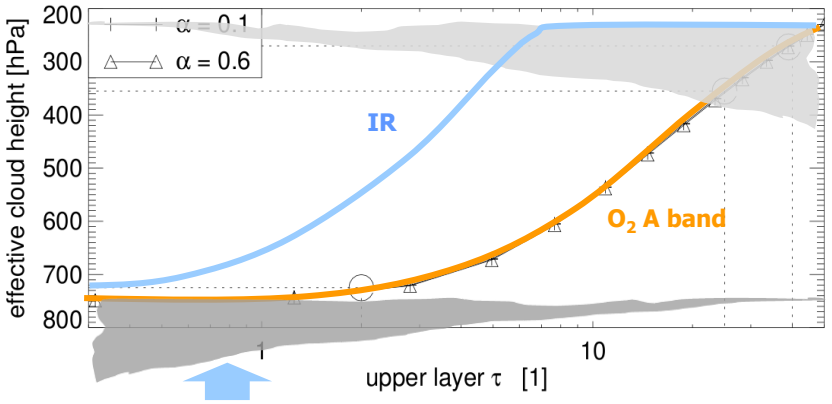
Refinement of O_2-A band cloud top pressure algorithm for METimage: Multi-layer detection and merging with Vis/IR

METimage Spectral:	
VII band	Central wavelength (µm)
VII-4	0.443
VII-8	0.555
VII-12	0.668
VII-15	0.752
VII-16	0.763
VII-17	0.865
VII-20	0.914
VII-22	1.240
VII-23	1.375
VII-24	1.63
VII-25	2.250
VII-26	3.74
VII-28	3.959
VII-30	4.050
VII-33	6.725
VII-34	7.325
VII-35	8.54
VII-37	10.69
VII-39	12.02
VII-40	13.345

- O_2 A-Band CTP: 1DVar (O.E.)
- x = [CTP, COT]
- $y = [\rho_{0.67/0.86}\ ,\ \rho_{0.763}\ /\ \rho_{0.752}]$
- $y(x) = LUT\ (\mathrm{COT, CTP, w_{10}, p_{surf}}, \Phi_3)$

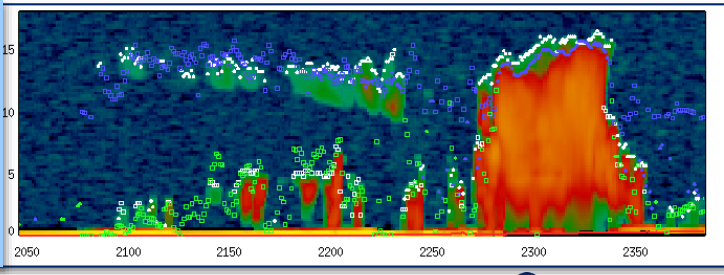
Include H_2O channel (absorbing) Detection by cost function?

No signal from Multi-layer cloud - but large effect on CTP



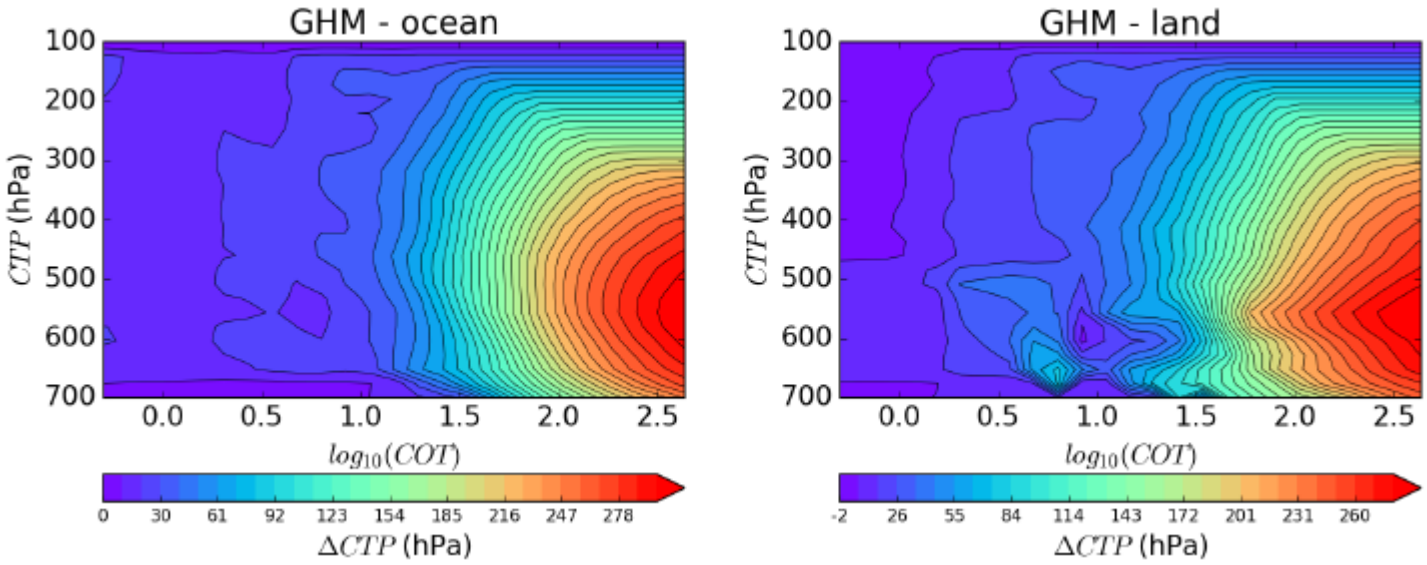
Established signal from Multi-layer cloud - Complementary response?

- VIS/IR Cloud Properties: 1DVar (O.E.)
- x = [CTP, COT, CRE, T_{skin}] (1-2 layers)
- $y = [\rho_{VIS}, BT_{IR}]$ (<18 channels (TBD))
- $y(x) = RT(ECMWF) + LUT\ (\mathrm{COT, CTP, CRE}, \Phi_3)$



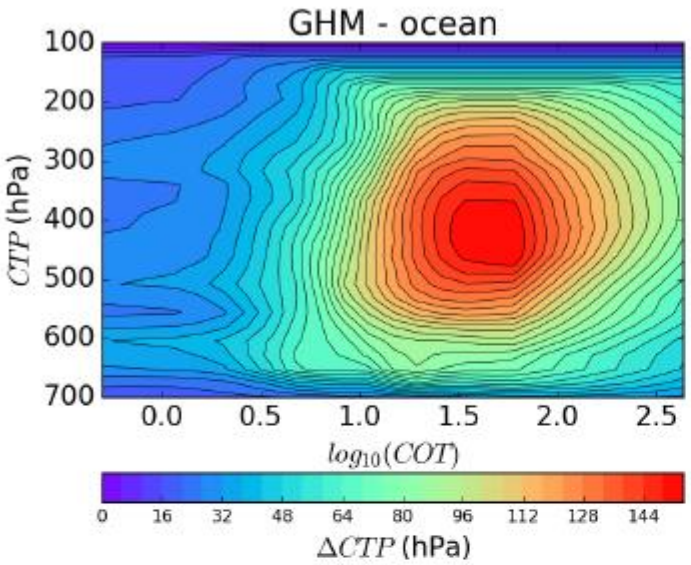
Refinement of O_2-A band cloud top pressure algorithm for METimage: Sensitivity to ice habit

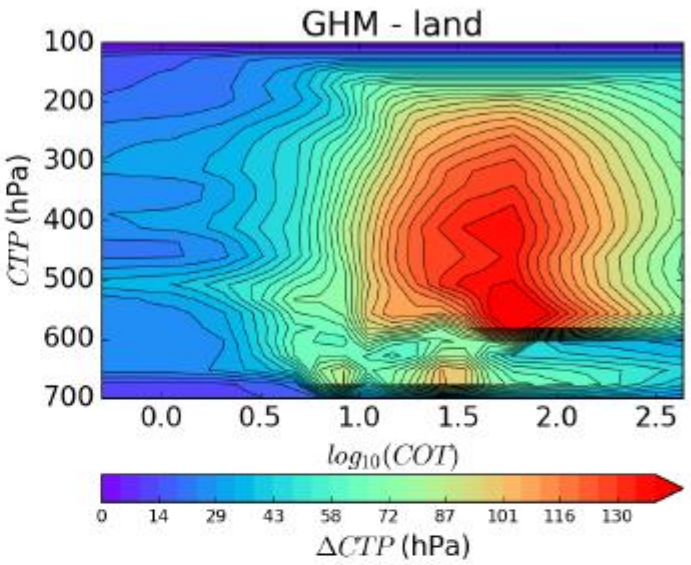
Retrieval Sensitivity very high for both land and ocean

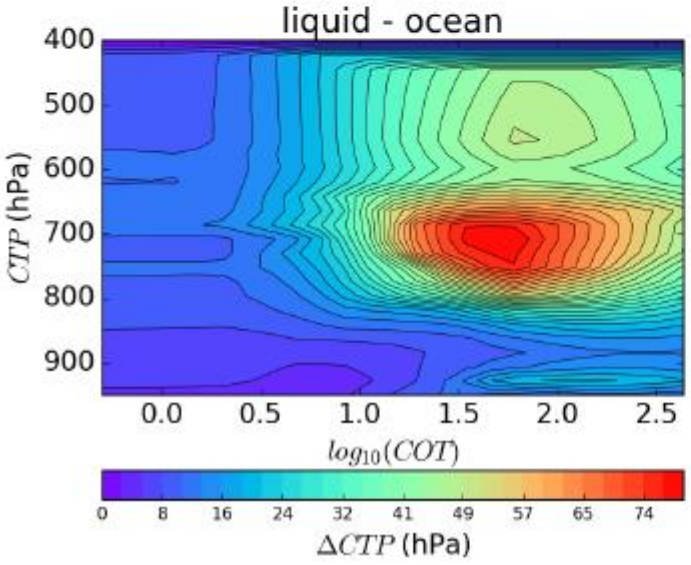


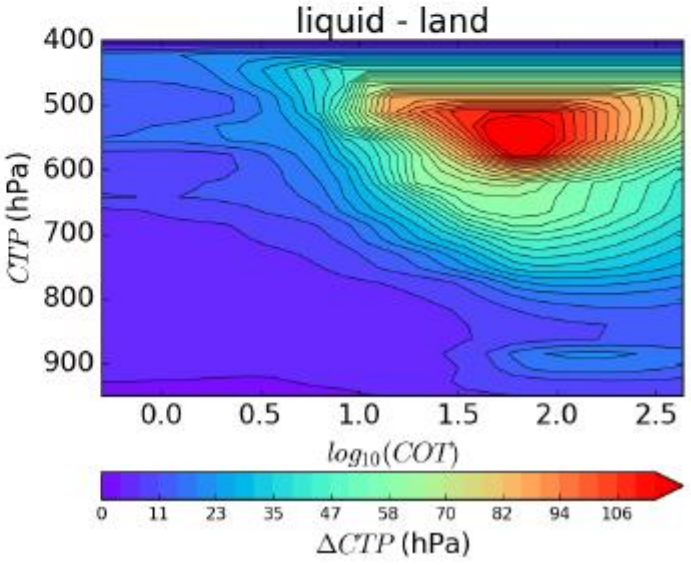
General Habit Mixture model (Baum et al. [2014] / Rough Hexagonal Mono-crystal (RHM, POLDER/PARASOL like model)

Refinement of O_2-A band cloud top pressure algorithm for METimage: Sensitivity to extinction profile









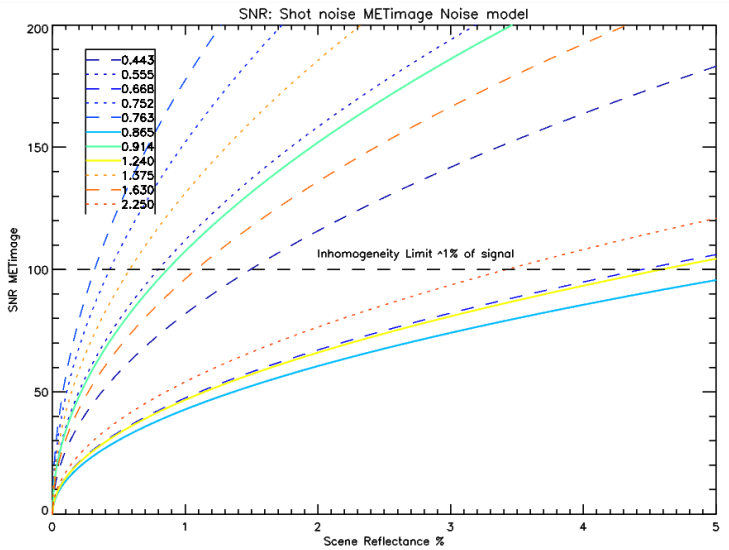
Retrieval Sensitivity High (higher for ice particles)

Refinement of O_2-A band cloud top pressure algorithm for METimage: Application to proxy data and remaining work:

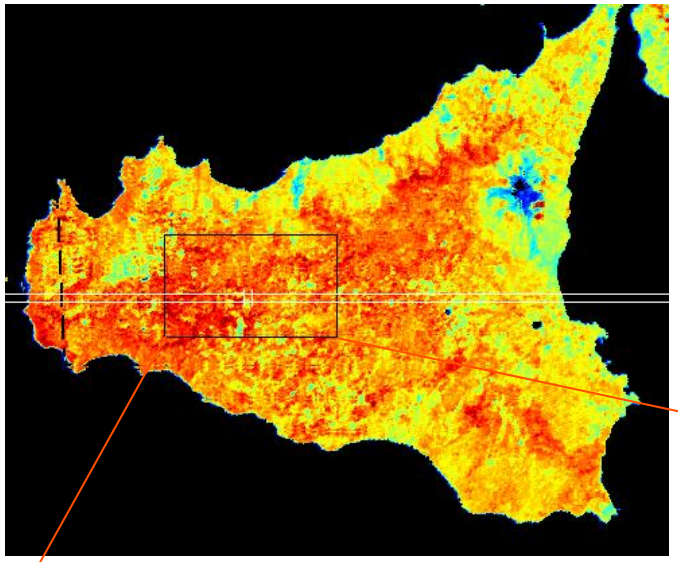
- Sensitivities in the real world to be examined using PARASOL/MODIS A-Train data and CPR/CALIPSO as reference
- Multi-layer cloud detection using 0.91 μm channel from 'posterior cost function' to be tested
- Scoping methodology to merge VIS/IR and O_2-band information
  - State vector extension/definition (+cloud geometrical thickness + extinction shape ...)
  - RT particularly for O_2-band
- Single-scatter separation (smaller LUTs = scope for state vector expansion)

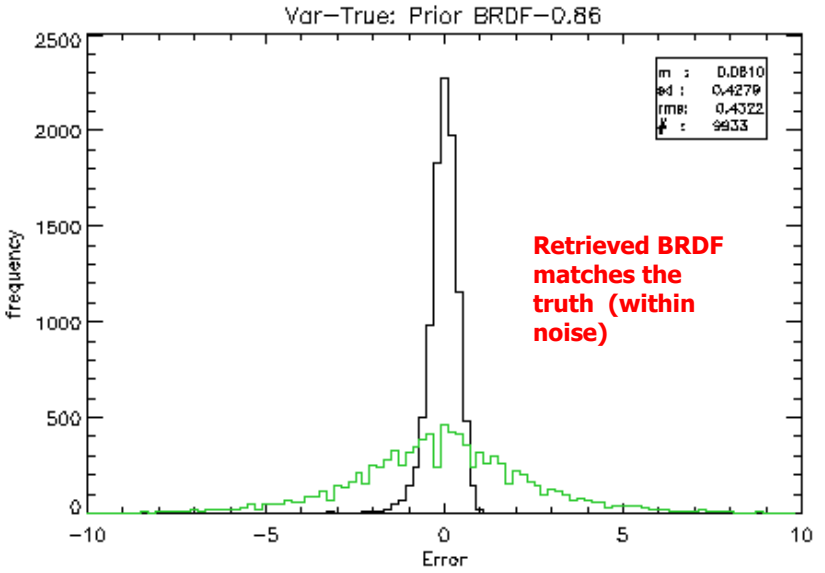
Total Precipitable Water from METimage:
ongoing developments for TPW-VIS

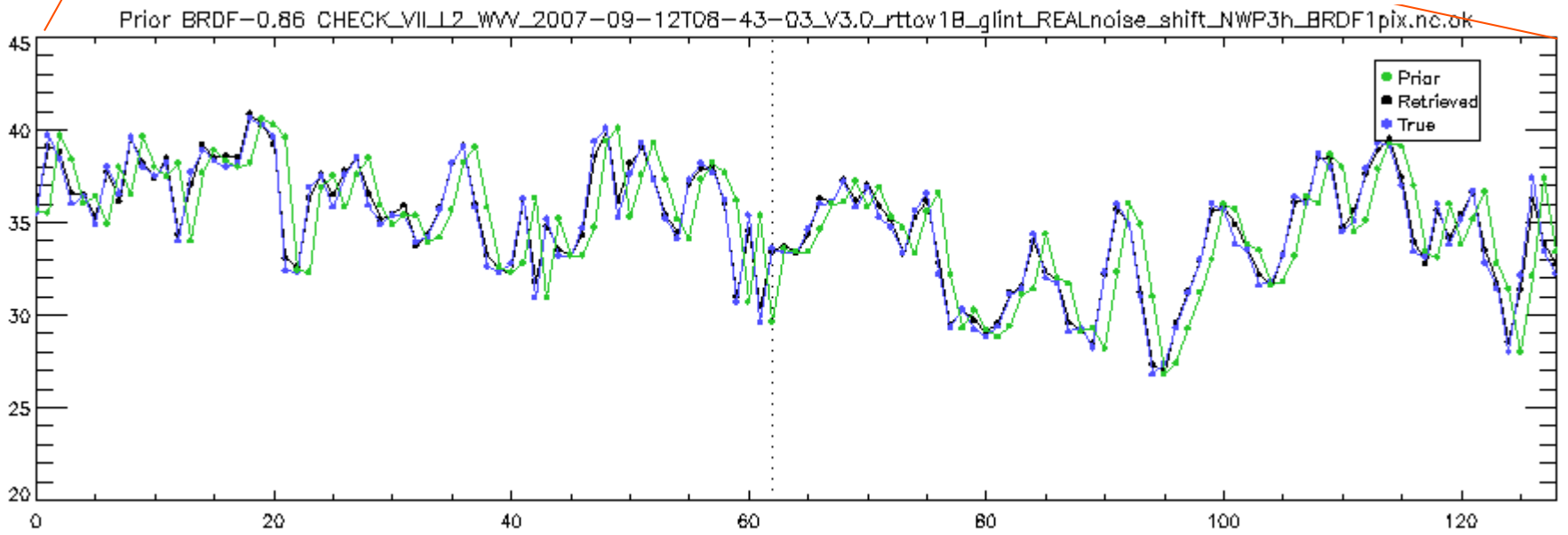
- Prototyping along the lines of MODIS/MERIS approach
- 1Dvar retrieval
- Measurement vector:
  - 0.91μm – TPW; 0.86μm,1.24μm – reference channels for BRDF
- State Vector: [Q(p), BRDF0.86, BRDF1.24, (AOD)]
- RTTOV-11; BRDF0.91 linear from BRDF0.86, BRDF1.24
- Prior:
  - Q(p) ECMWF short term forecast, static covariance
  - BRDF MODIS 16-Day L3 Global 500m (MCD43A1), static covariance
  - AOD CAMS short term forecast, static covariance
- Test Data
  - METimage SDS test data (including cloud/aerosol)
  - Simulations (excluding cloud/aerosol)
- Noise model:
  - SNR (simple shot-noise based on spec) +
  - Co-registration 0.6% +
  - Inhomogeneity 1%



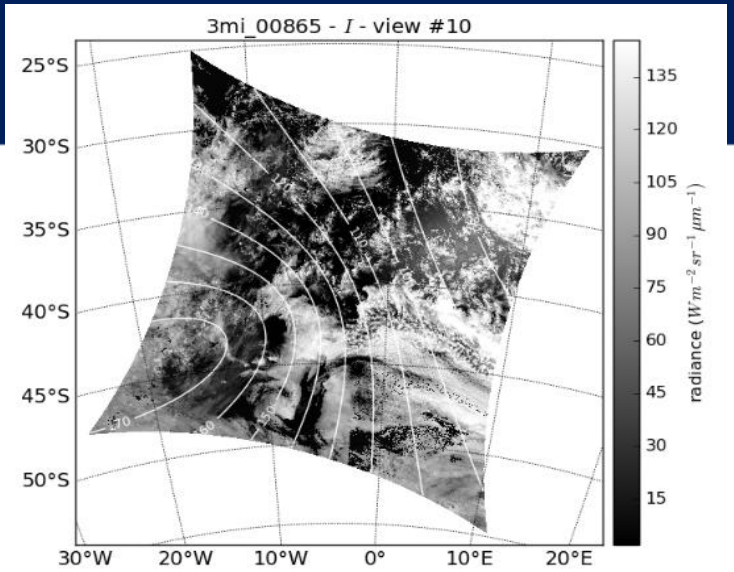
TPW-VIS test retrievals: BRDF (Prior 1 pixel shift from truth ~ 10% BRDF error)







Multi-viewing multi-channel multi-polarisation Imaging (3MI)



Objectives / products

- Aerosol – optical thickness, particle size, type, height, absorption
- Volcanic Ash
- Cloud phase, height, optical depth
- Surface albedo

Key performances

- 12 channels: 0.41 – 2.13 µm
- 3 polarisations: 0°, 60°, -60°
- 14 views
- Radiometric bias: 3%
- SNR: 200
- Spatial sampling: 4 km
- Push-broom scan (2200 km swath)

Applications benefitting

- Climate monitoring
- Nowcasting
- Air quality

Breakthrough:

- **Enhanced spatial sampling (4 km)**
  - Improves separation of cloudy areas
- **12 spectral channels (9 polarised), extending into the SWIR**
  - Better aerosol characterisation
- **Higher angular resolution (14 views)**
  - Better phase function characterisation

Slide: 24

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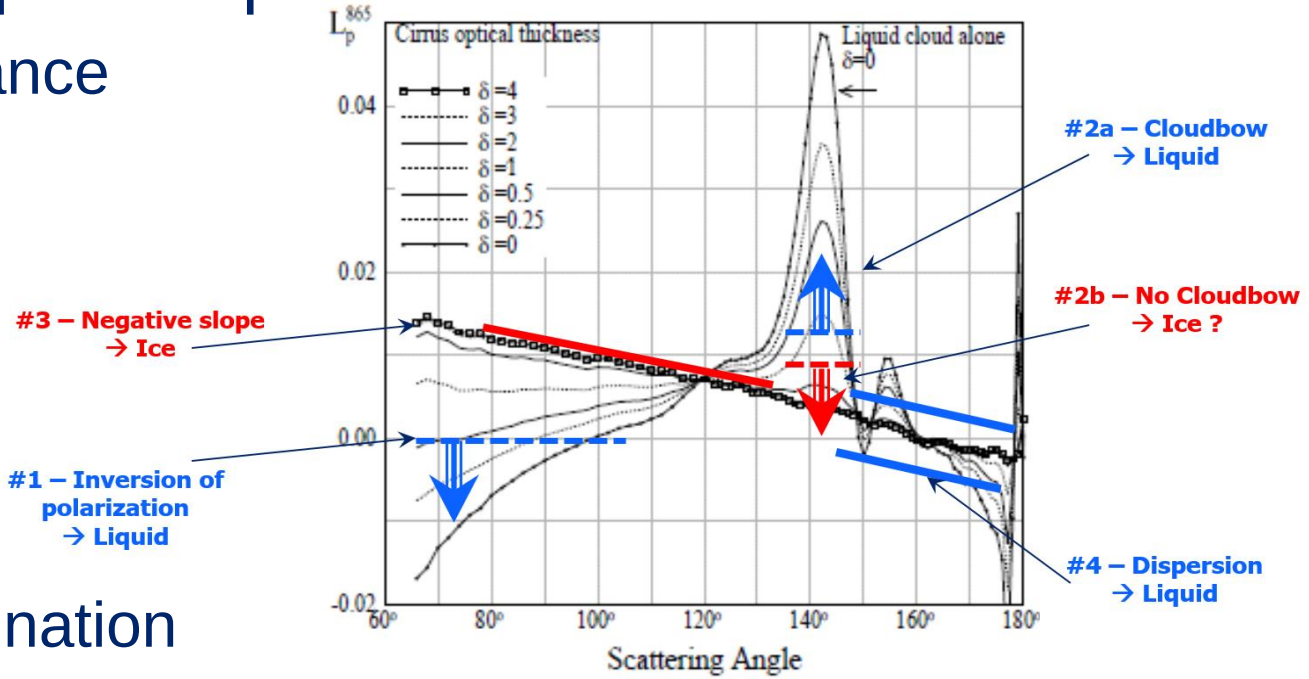
3MI cloud algorithm development

- The proposed improved algorithm is fully derived from the PARASOL + MODIS synergetic retrieval
- Main improvements :
  - Cloud detection : including the use of spectral signatures together with polarisation and multi-directionality
  - Phase identification: use of the full signature polarised+spectral+directional
  - Estimation of the albedo/COT: more optimised band at 0.555 µm
  - Spectral integration
  - Particle effective radius :
    - Droplet : Derived from primary + supernumerary cloud bows in polarisation for 3 bands (previously primary bow for 1 band)
    - Crystal : Derived from a NIR/SWIR bi-spectral retrieval
  - Vertical structure : combination of Rayleigh and oxygen pressures as well as their angular variations
  - Provision of cloud geometrical height, and integrated shortwave albedo

3MI Cloud algorithm development - improvements

- Example of the improved phase identification

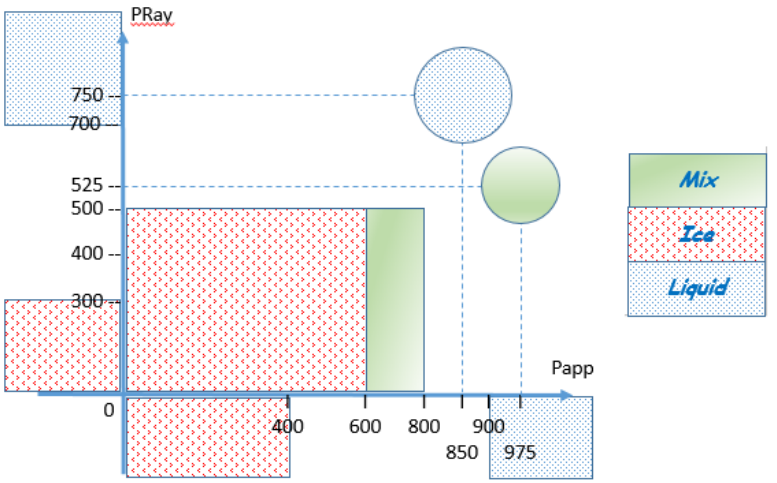
  1) Polarized reflectance



  2) Directional combination

  3) Reclassification of undetermined cases

Rayleigh versus Apparent pressures



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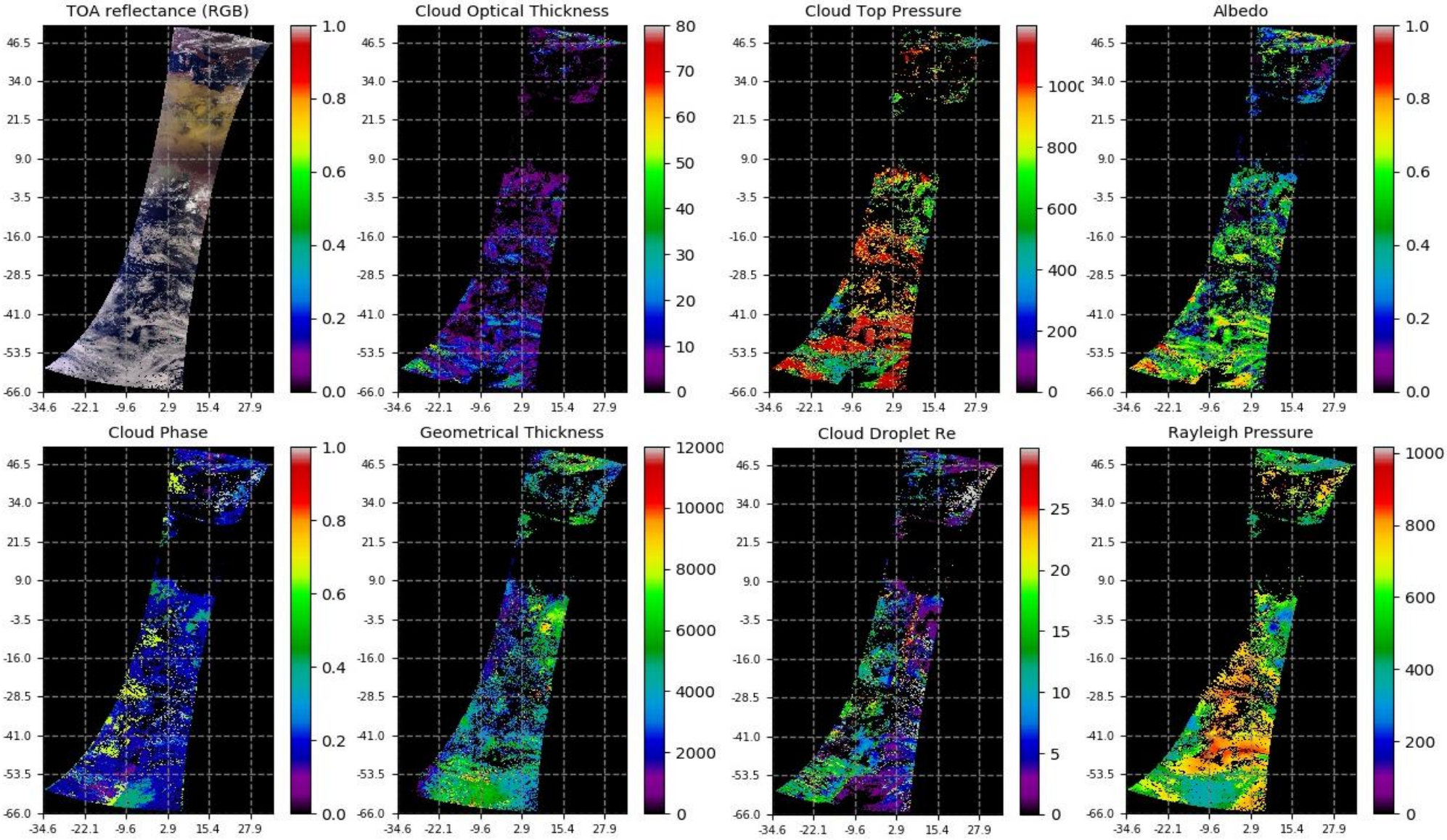
3MI Cloud algorithm development - Prototype

First 3MI test retrievals based on simulated top of atmosphere radiances



3MI aerosol algorithm development

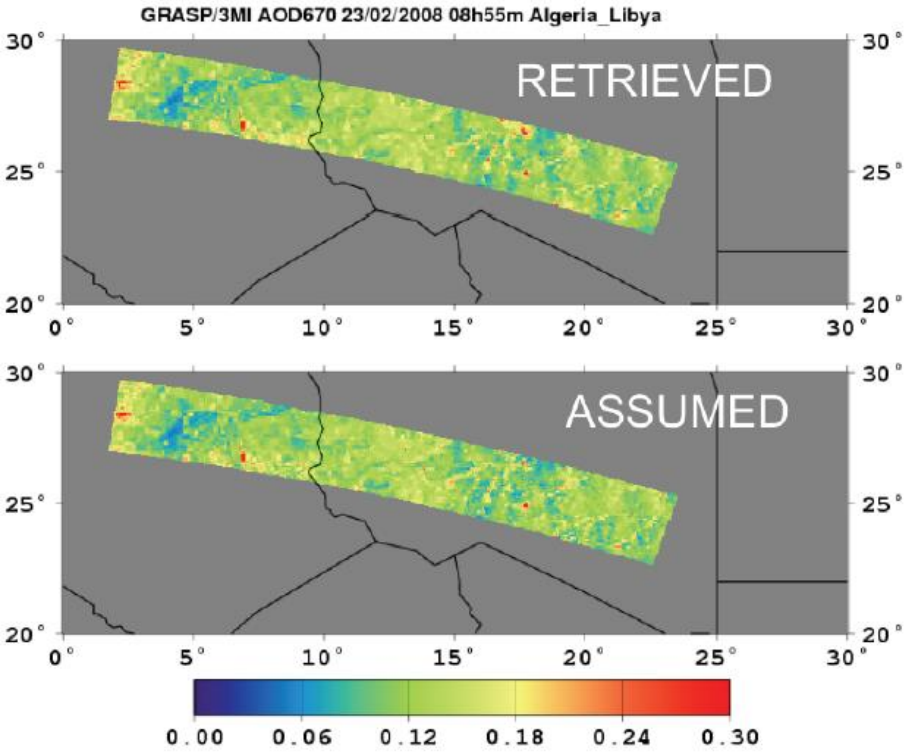
- The proposed improved algorithm is fully derived from the PARASOL retrieval and based on GRASP (Generalized Retrieval of Aerosol and Surface Properties)

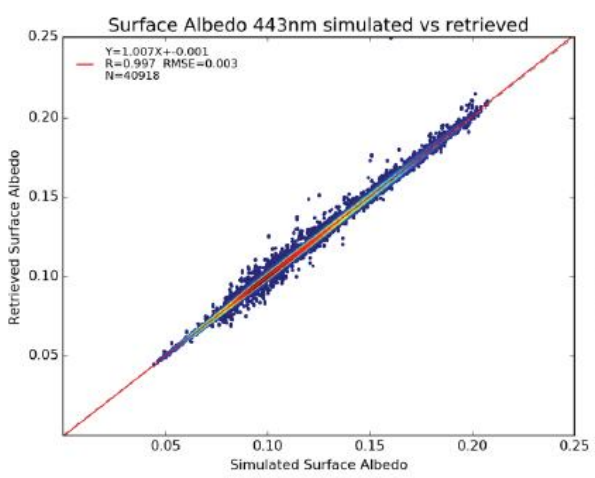
- Main improvements :
  - Full available 3MI information : polarised + spectral + directional
  - 1DVar allows the simultaneous retrieval of surface and aerosol properties
  - Possible consideration of multi-temporal and multi-spatial constraints under assessment

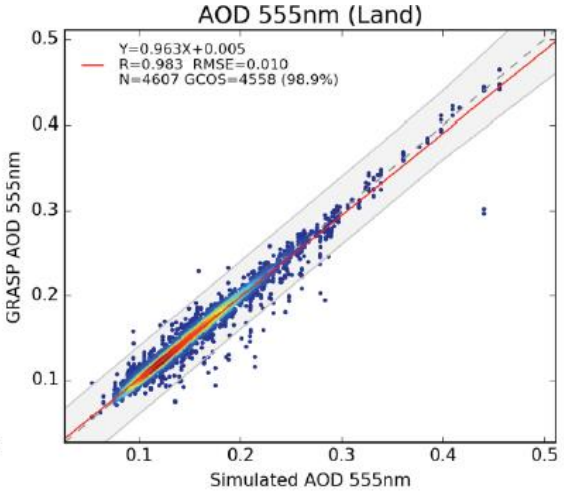
- The algorithm has to be optimised to fit the need for NRT
  - Trade-off done on different configurations
  - Identification of coding optimisation (RT calculation…) ongoing

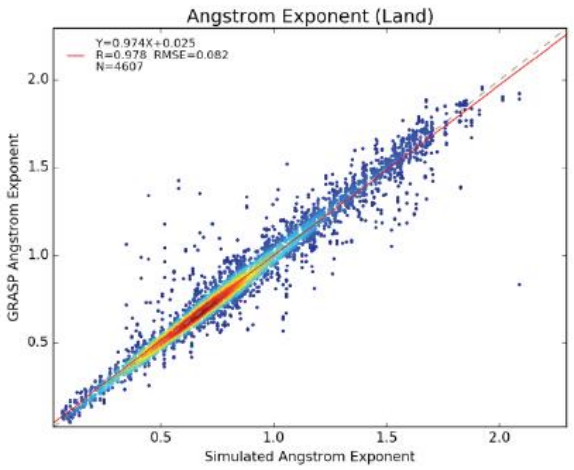
3MI Aerosol algorithm development - improvements

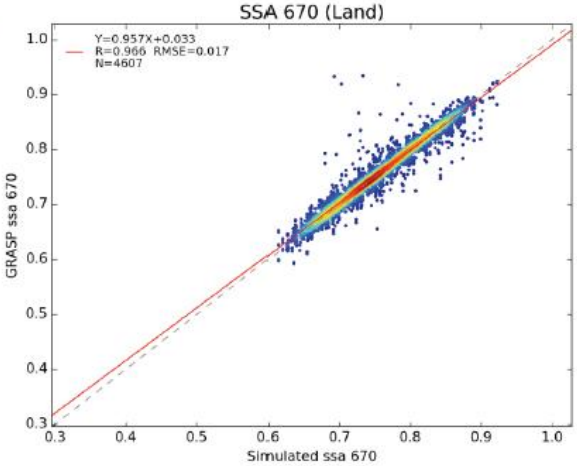
- GRASP retrieval from simulated top of atmosphere radiances



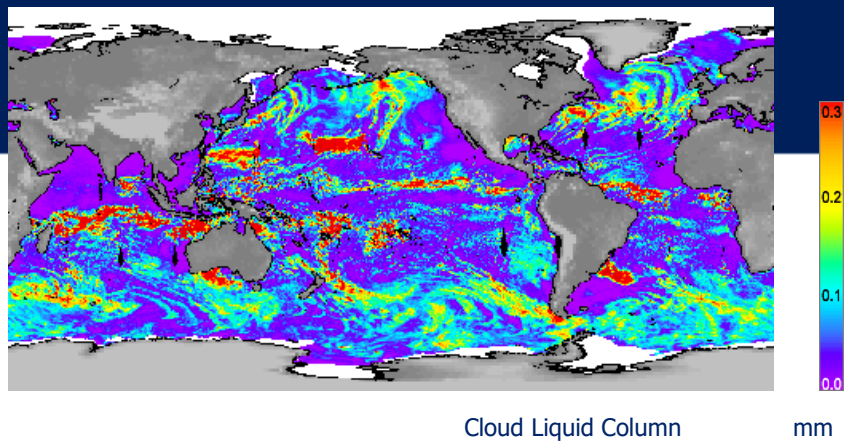








Micro-wave imaging (MWI)



Cloud Liquid Column mm

Objectives / products

- Precipitation and cloud products
- Water vapour imagery
- Sea-ice, snow, sea surface wind

Key performances

- 18 channels: 18.7 – 183 GHz
- Dual polarisation (V, H) up to 89 GHz
- V polarisation at higher frequencies
- Radiometric accuracy: 1 K
- Radiometric sensitivity: 0.6 – 1.2 K
- Footprint size: 10 – 50 km
- Spatial sampling: 7 km
- Conical scan

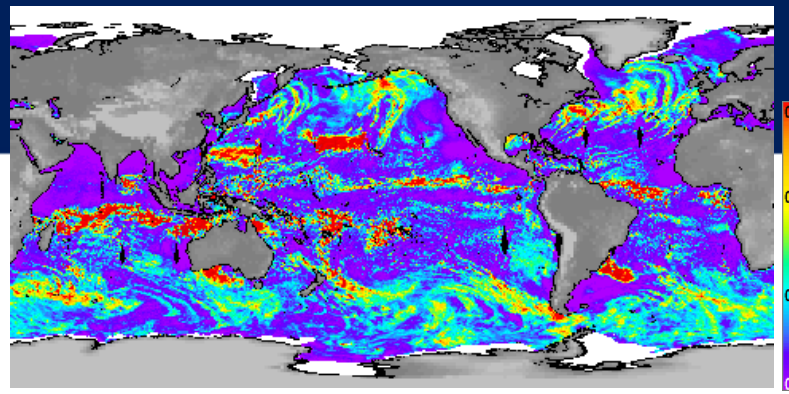
Applications benefitting

- Numerical weather prediction
- Nowcasting
- Oceanography
- Hydrology
- Climate monitoring

Breakthrough: 18 channels

- **Continuity of key microwave imager channels for weather forecast**
- **Inclusion of dedicated sounding channels (118.75 GHz)**
  - Enhanced precipitation measurements through inclusion of dedicated sounding channels
- **Extended suite of 183.31 GHz channels**
  - water-vapour and cloud profiling

Micro-wave imaging (MWI)



Cloud Liquid Column mm

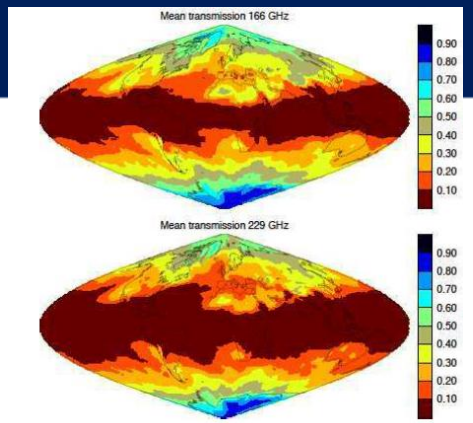
Level 1B

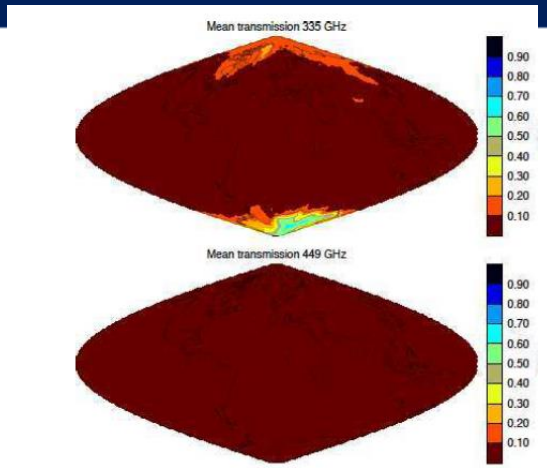
- **Being implemented following industrial ATBD**

Level 2 products under development

- **Centrally generated: cloud liquid water path**
- **SAFs: rain products, sea ice products, wind seed over ocean**

Ice cloud imaging (ICI)





Objectives / products

- Cloud products, in particular ice clouds
- Snowfall detection and quantification
- Water-vapour profiles and imagery

Key performances

- 11 channels: 183 – 664 GHz
- Single polarisation (V) for all channels
- Dual polarisation (V, H) at 243 and 664 GHz
- Radiometric accuracy: 1 – 1.5 K
- Radiometric sensitivity: 0.6 – 1.9 K
- Footprint size: 15 km
- Spatial sampling: 7.5 km
- Conical scan

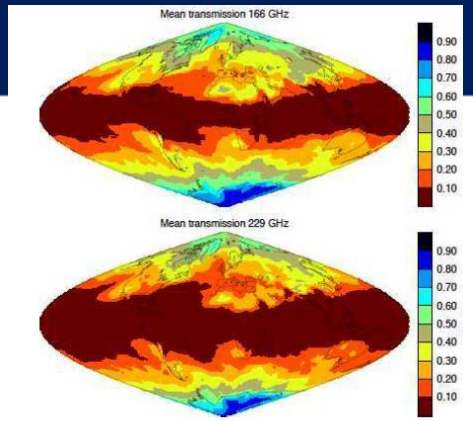
Applications benefitting

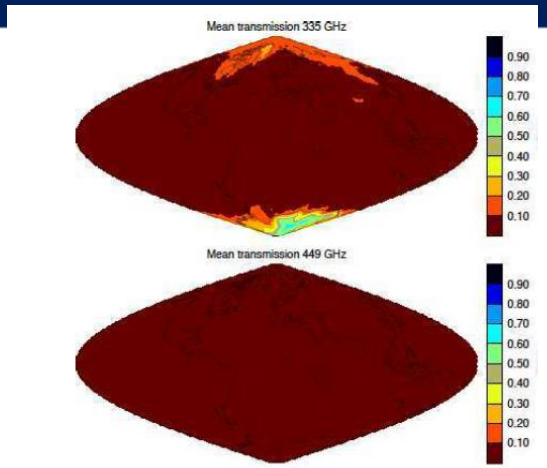
- Numerical weather prediction
- Nowcasting
- Hydrology
- Climate monitoring

Breakthrough: 11 channels

- **Establishes operational ice-cloud imaging mission**
- **Support of weather forecast, hydrology, and climate monitoring**

Ice cloud imaging (ICI)





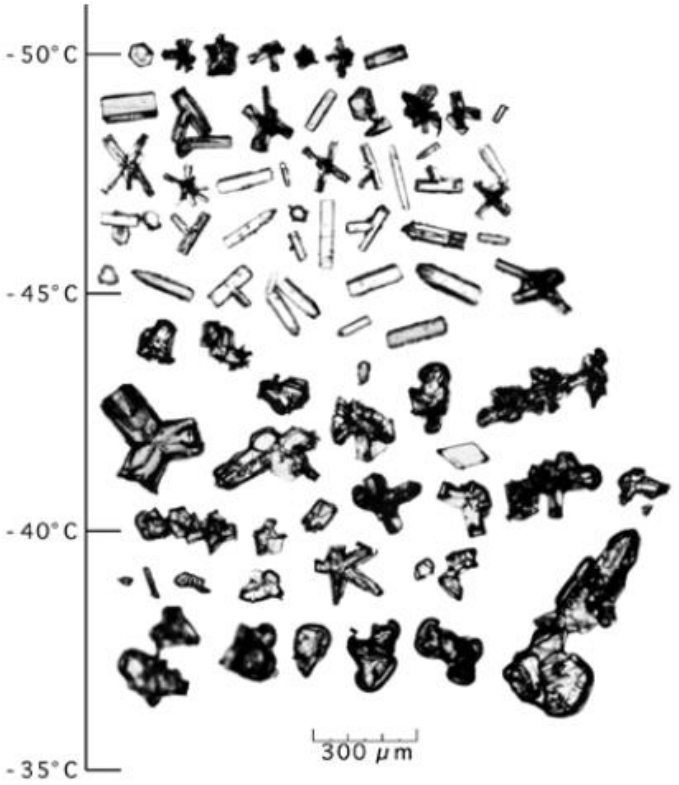
Level 1B

- **Being implemented following industrial ATBD**

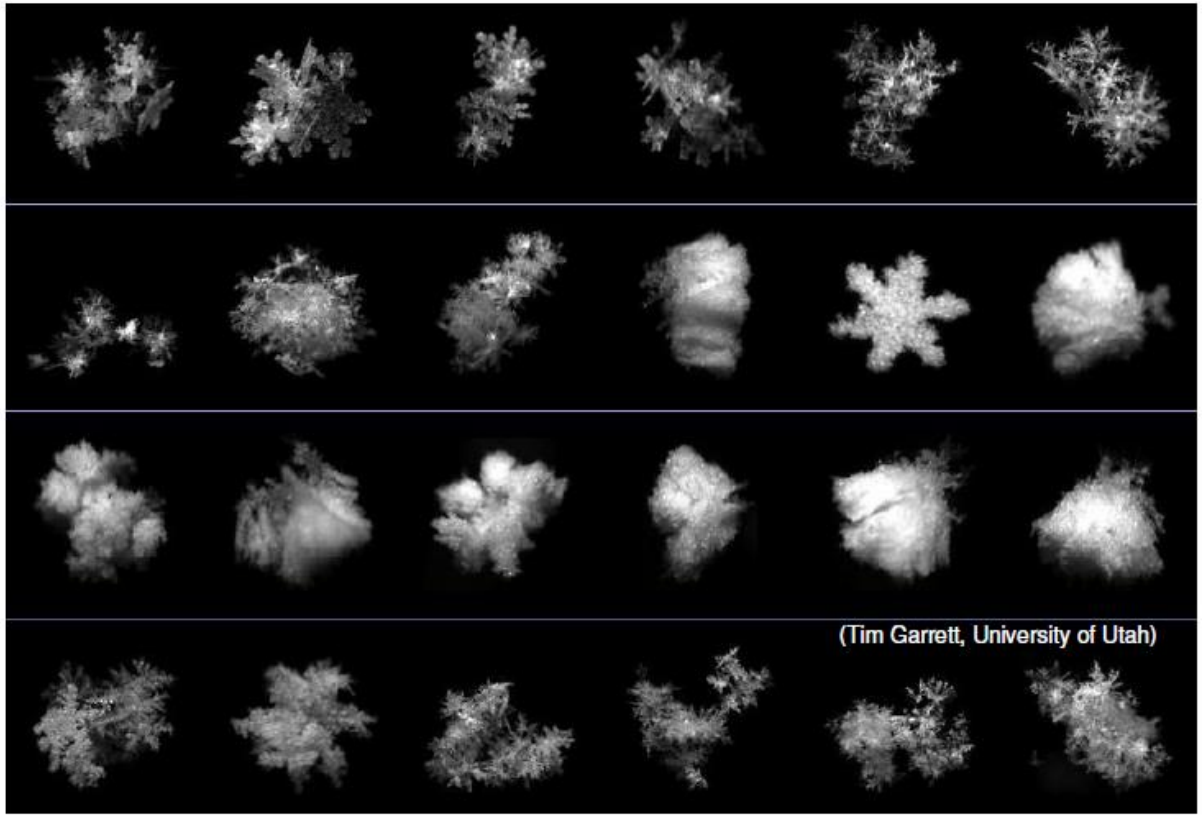
Level 2 products under development

- **Centrally generated: cloud ice water path**
- **SAFs: snowfall products**

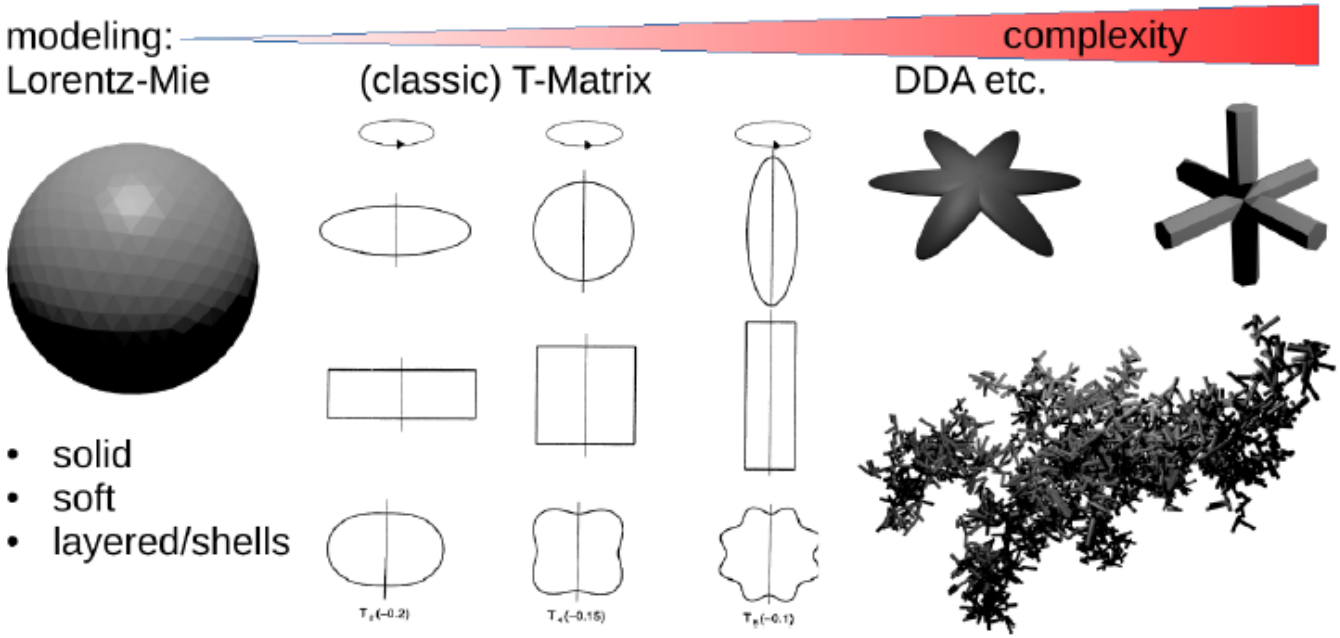
Challenge: development of an advanced SSP database for frozen hydrometeors



(Heymsfield and Miloshevich, JAS, 2003)



Development of particle models



Situation at beginning of the study:

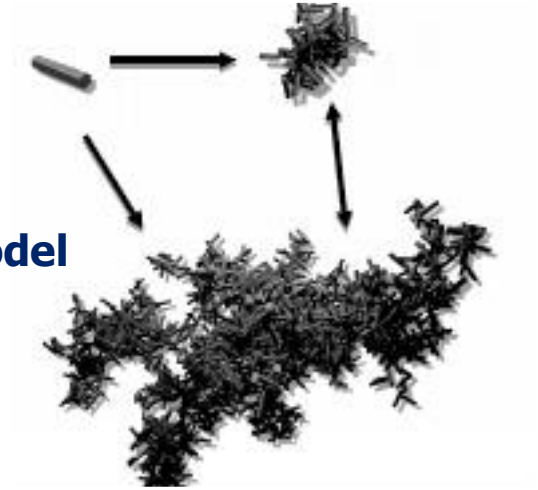
- **Liu database: best general one, up to 340 GHz, with simple sector-snowflake**
- **Hong database, only one above 340 GHz, but with outdated refraction index for ice**
- **Oriented particles: only for radar and some example data**

Shape data

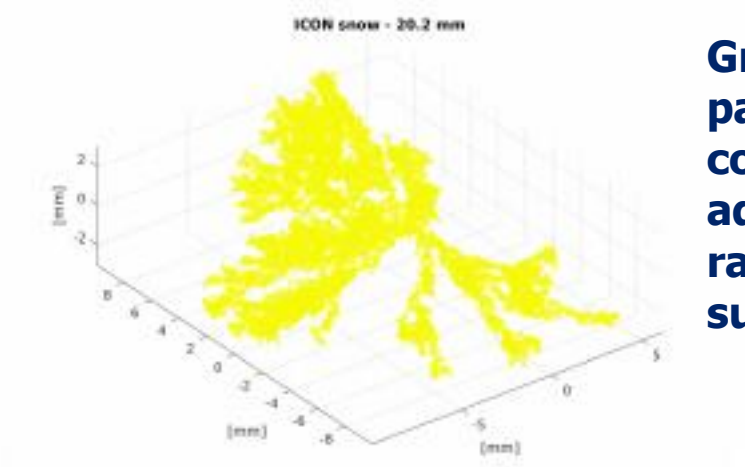
- Particle modelling
- Models developed: Snowflake toolkit, Rimecraft (modelling partial melting as well)
- Third party sources:
  - Evans et al. 2012
  - Tyynelä et al. 2011
  - Hong et al. 2009
  - Liu 2008

Snowflake toolkit

Iterative stochastic collision model

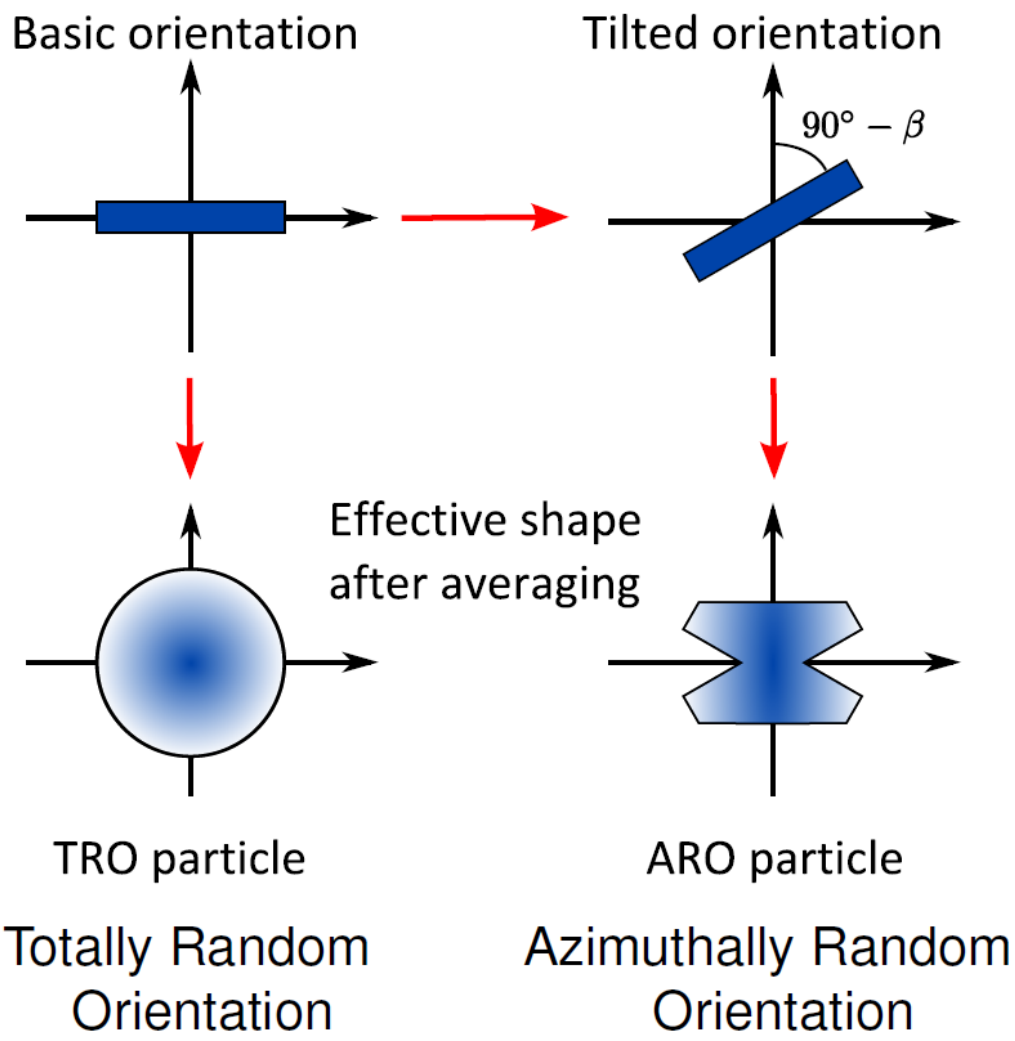


Rimecraft



Growth of the particle controlled by adding dipoles randomly in successive layers

Particle orientation



TRO: spherical symmetry

Extinction matrix: one independent value, independent of incidence direction

ARO: cylindrical symmetry

Extinction matrix: three independent values

Scattering dependent on incidence direction

Extinction matrix depends on tilt angle β and incidence angle

Description of oriented particles has a huge computational impact due to more degrees of freedom

New database prepared

Scattering calculations based on Discrete Dipole Approximation (DDA) method

Advantage: it can deal with arbitrary morphology of the particles

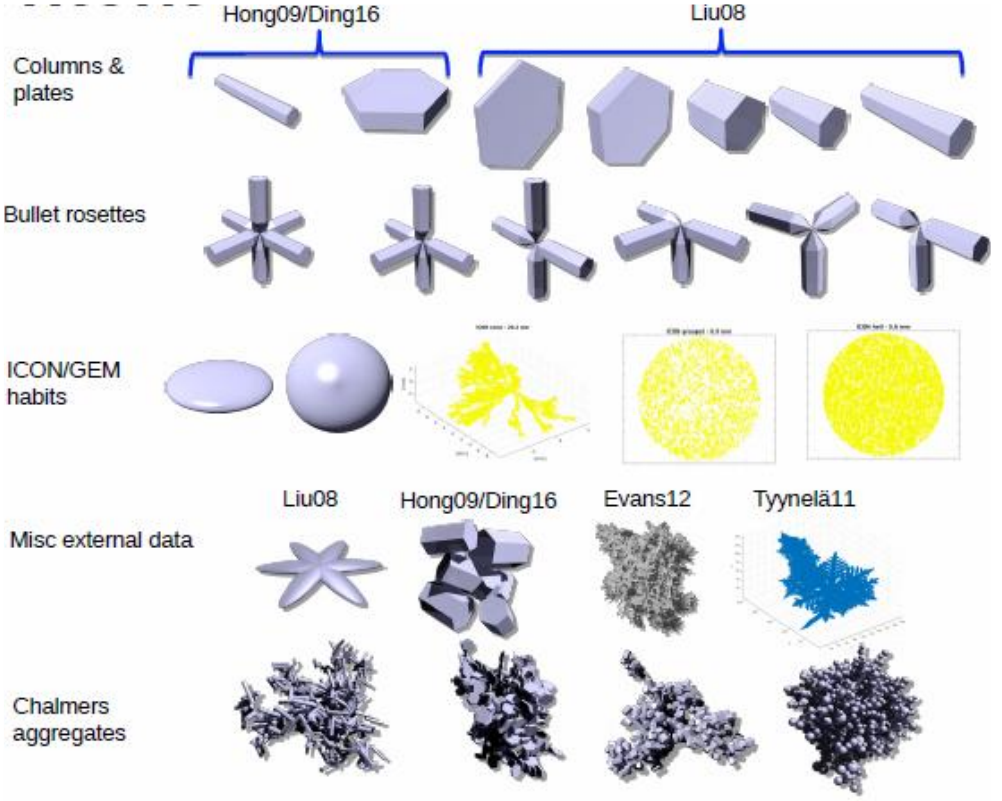
33 habits in TRO, 1 in ARO

34 frequencies: [1, 886] GHz

3 temperatures : 190, 230, 270 K

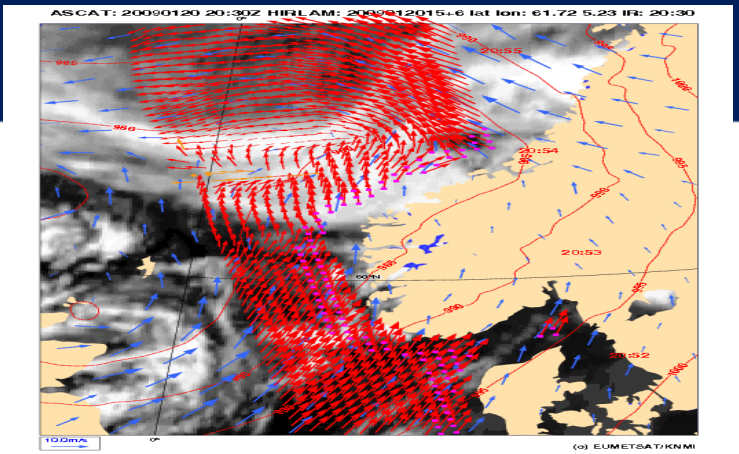
Refractive index by Mätzler 2006

Extinction, absorption and scattering matrix data with complete polarisation information was produced assuming random orientation and stored in NetCDF4 files



Code snippet to make use of the database together with RTTOV-SCATT is available with the data

Scatterometry (SCA)



Objectives / products

- Ocean surface wind vectors
- Soil moisture
- Snow equivalent water
- Sea-ice type

Key performances

- C-band carrier frequency
- VV + VH polarisation
- Measurement range: 4 – 40 m/s
- Radiometric resolution: 3%
- Spatial resolution: 25 km
- Dual swath: 600 km each
-

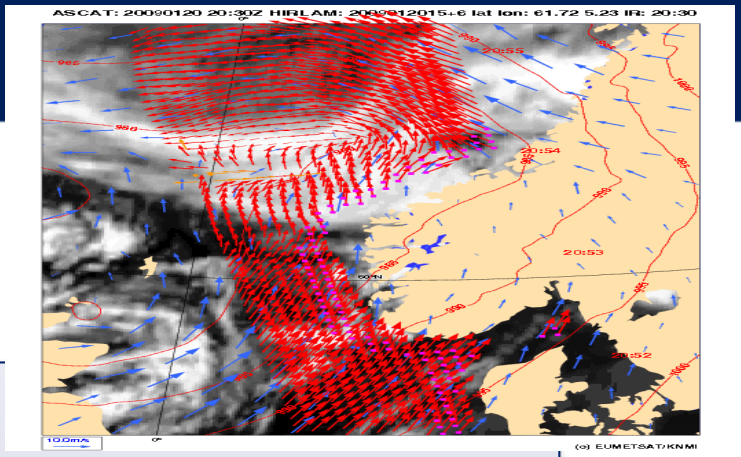
Applications benefitting

- Numerical weather prediction
- Nowcasting
- Oceanography
- Hydrology
- Climate monitoring

Breakthrough

- **Increase of spatial resolution to 25 km**
  - Better approach of coast lines
- **Increase of swath width to ~1200 km**
  - Enhanced coverage
- **Addition of VH polarisation**
  - Covers higher wind speeds without saturation, will benefit observation of tropical and extra-tropical storms

Scatterometry (SCA)



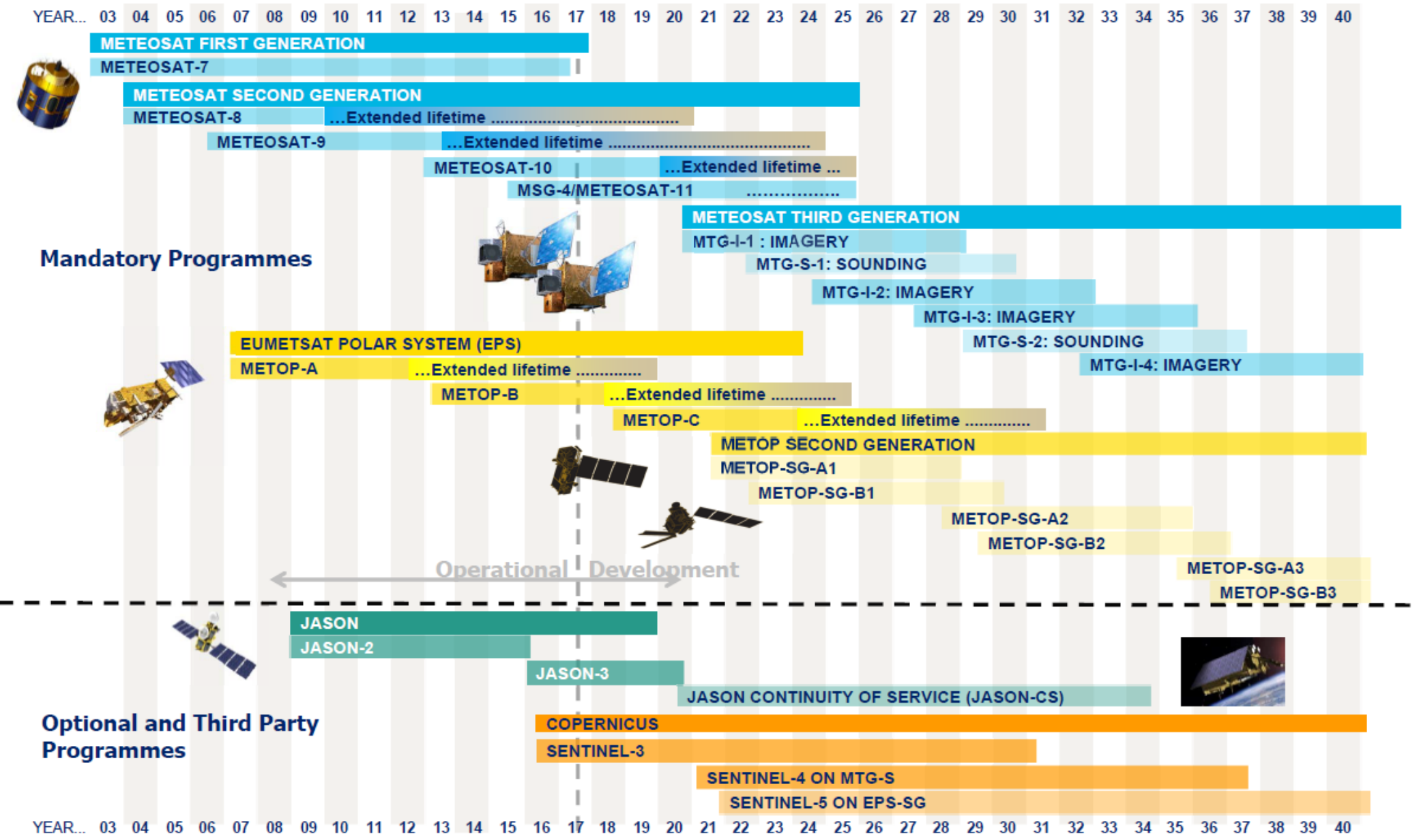
Level 1B

- Cross-polarisation signals are subject to errors due to the Faraday rotation in the Earth atmosphere
  - Dependent on total electron content (TEC)
  - Dependent on Earth magnetic field
- An algorithm has been proposed to identify and correct for the effect
  - Input are NRT TEC predictions made by ESA
  - Data are will be flagged accordingly
  - A correction is appended to the data that can be applied by the users if deemed useful

Summary

- Algorithm developments for EPS-SG are well on track for continuity and new missions' Day-1 products
- Further developments are sketched and under development for Day-2 implementation as soon as possible after commissioning
- Cal/Val planning is ongoing and will be concluded at System CDR for implementation of tools in Phase D
- Importance of early user involvement during commissioning phase has been recognised important, based on experience in EPS first generation

Schedule


YEAR... 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
METEOSAT FIRST GENERATION
METEOSAT-7
METEOSAT SECOND GENERATION
METEOSAT-8
...Extended lifetime .....
METEOSAT-9
...Extended lifetime .....
METEOSAT-10
...Extended lifetime ...
MSG-4/METEOSAT-11
.....
METEOSAT THIRD GENERATION
MTG-I-1 : IMAGERY
MTG-S-1: SOUNDING
MTG-I-2: IMAGERY
MTG-I-3: IMAGERY
MTG-S-2: SOUNDING
MTG-I-4: IMAGERY
Mandatory Programmes
EUMETSAT POLAR SYSTEM (EPS)
METOP-A
...Extended lifetime .....
METOP-B
...Extended lifetime .....
METOP-C
...Extended lifetime .....
METOP SECOND GENERATION
METOP-SG-A1
METOP-SG-B1
METOP-SG-A2
METOP-SG-B2
METOP-SG-A3
METOP-SG-B3
Operational
Development
JASON
JASON-2
JASON-3
JASON CONTINUITY OF SERVICE (JASON-CS)
Optional and Third Party Programmes
COPERNICUS
SENTINEL-3
SENTINEL-4 ON MTG-S
SENTINEL-5 ON EPS-SG
YEAR... 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40